New Generation of Self Supporting Optical Fibre Aerial Cables

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0. Abstract

This contribution outlines two new approaches for optical fibre aerial cables with metallic armouring for high tension power lines. A ground wire with a central hollow pipe is described in which in a later stage optical fibre elements can be blown in over some km single length. The fibre element for up to 6 fibres has only a diameter of 1.3 mm but sufficient strength for the blowing-in operation and excellent temperature behaviour. The other approach described here is an optical fibre ground wire with the same diameter, weight, strength, and short circuit current capacity as Al/St 50/30 ground wire used on 110 kV overhead lines. The optical fibre buffer element formed with a steel tube is stranded over a Al profile wire together with Ay and Aw wires.

1. Introduction

The optical transmission technique with optical fibres in self supporting aerial cables is of great interest for power utilities, because the transmission tasks like data transmission, ISDN and protection signals are more and more digital. Moreover for this transmission medium no electromagnetic interference occurs and the broadband characteristics of the optical fibres together with the low attenuation allows fast data transmission, an enormous increase of available transmission channels, and long repeater spacing. This contribution describes new generations of self supporting optical fibre aerial cables. One construction is designed for the later incorporation of optical fibres and the second construction is designed for replacing old earthropes on old and weak power lines by an optical fibre aerial cable.

2. State of the Art

The first optical fibre aerial cables were installed in 1978 on a 110 kV line. The metal armoured aerial cable consisted of 3 star quads and 2 optical fibres. This 1.6 km long length was installed in two pieces at the lower traverse of the towers. Since that time this route is in service without any difficulties. In further projects *double* armoured aerial cables were installed. Because of torsion problems the lay length of both armour layers were chosen in such a way that the resulting torsion moment becomes negligible. In 1981 a 8 km long route was erected. The cable contains besides 2 optical fibres 8 star quads. The attenuation in a temperature range between -15 and +40 °C as measured during service shows constant temperature independent behaviour. For the 20 kV lines first optical fibre phase ropes were installed in 1985.

Also totally dielectric self supporting aerial cables were installed between the beginning of the eighties and 1984 on 20 kV and also high tension towers up to 380 kV. Even if the optical transmission characteristics behaves constantly over all environmental conditions there is only little future for those cables. By their different me-

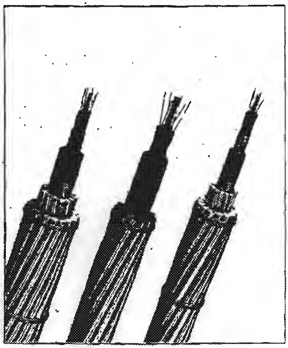


Fig. 1: Standard optical fibre aerial cables

chanical behaviour compared to phase ropes with respect to sag, additional loading, vibration and swinging behaviour these cables are so different that there is only narrow space on the power line poles. That is true, even if the electrical problems of plastics and electrical AC fields is solved [1], [2].

Therefore since 1986 annually some hundred kilometre of optical fibre aerial cables with metallic armouring are laid in the net of the German power utilities [3].

The construction of those optical fibre aerial cables is designed for the wide temperature range and the high forces which acts on the cable during its life. The best possibility to prevent optical fibres from mechanical forces and to give them sufficient place for free movement is the loose tube technique. Depending on the number of fibres per cables one or two fibres are incorporated in a tube of approximately 2 mm diameter. To prevent that humidity comes to the primary coated fibres and to give the fibres a floating surrounding these tubes are filled with a thixotropic jelly. Six of these tubes are stranded around a central strength element made of fibre reinforced plastic (FRP). By the choice of the lay length, the operational range with respect to constrain and elongation can be chosen. Moreover for single mode fibres the effect of microbending which lead to additional attenuation at 1550 nm must be taken into account. The variation of length by lateral forces and temperature are calculated from the formula

Parameter/Typ (Ay/Aw)	Dimension	232/44-22.5	75/25-7.5	112/28-11.0
Diameter	mm	24.1	16.4	18.8
Weight	kg/km	1046	450	551
Armouring layers		2	1	2
portion Aw	mm^2	44.2	24.8	28.3
portion Ay	mm^2	232.1	74.7	111.8
Young's modulus	kN/mm^2	78.3	84.8	79.6
Calculated breaking force	kN	116.4	52.8	64.1
Permissible strain	N/mm^2	171	202	186
Mean permissible strain (EDS)	N/mm^2	71	81	75
Maximum permissible strain	N/mm^2	341	412	376
Thermal expansion coefficient	$10^{-6}\ K^{-1}$	18.5	16.3	15.9
DC resistant	Ω/km	0.136	0.407	0.280
Rated short circuit current,	$kA \cdot s^2$	22.6	7.5	11.0

Table 1: Data of standard optical fibre aerial cables

$$\epsilon = \sigma/E+(\theta-20)T_k$$

ϵ = elongation, relative length variation
σ = strain
E = Young's modulus
T_k = thermal expansion coefficient
θ = temperature (°C)

Type of rope		Temperature and additional load (Z)										
		-5+Z/2	-5+Z	-20	-10	-5	+0	+10	+20	+30	+40	+50
Phase Rope	Sag m	11.77	12.12	10.84	11.21	11.39	11.57	11.92	12.26	12.60	12.93	13.57
Al/St 265/35	Strain N/mm^2	54.8	73.9	46.7	45.3	44.5	43.8	42.5	41.3	40.2	39.2	37.3
Aerial Cable	Sag m	12.48	13.34	10.87	11.28	11.45	11.61	11.82	12.22	12.53	12.82	13.40
Ay/Aw 75/25-7.5	Strain N/mm^2	122.3	183.8	80.9	78.8	77.5	76.5	74.5	72.6	70.9	69.2	68.2
Aerial Cable	Sag m	12.08	12.65	10.89	11.24	11.41	11.58	11.82	12.25	12.57	12.89	13.51
Ay/Aw 112/28-11.0	Strain N/mm^2	78.8	103.8	54.4	52.8	52.0	51.2	49.8	48.4	47.2	46.0	43.9
Aerial Cable	Sag m	11.80	12.16	10.86	11.22	11.40	11.57	11.92	12.26	12.59	12.92	13.58
Ay/Aw 232/44-27.5	Strain N/mm^2	83.3	79.9	52.4	50.7	49.8	49.2	47.7	46.4	45.2	44.1	42.0

Table 2: Comparison of sag for phase rope and different optical fibre aerial cables

For these aerial cables one can calculate more or less independent from the armouring a change of length in the order of a maximum of 2 ‰ in the interesting operational range. To this value an additional elongation of about 1 ‰ must be added which results from the setting of the armouring. By this the cable construction must consider an operational range of about 4 ‰. Over this core a polyethylene sheath is extruded with high precision which is the basis for the one or two layer armouring of aluminium alloy and aluminium clad steel wires. By a ratio of 1 to 4 of these wires the mechanical behaviour and temperature elongation of these aerial cables is comparable to those of the phase ropes. Table 1 and Figure 1 shows the mechanical data respectively the outfit of typical optical fibre aerial cables. As shown in Table 2 these aerial cables can be installed with the same sag over the operational range as conventional phase ropes.

By numerous measurements it was shown that these aerial cables show no change in attenuation over the temperature range of -40 to +70 °C as well as with loading far beyond the permissible strain.
But these standard aerial cables with a diameter in the range of 15 to 25 mm diameter depending on the number of fibres and especially the kind of armouring can be installed only on newer power lines. In case of old towers it is normally not possible to install an additional aerial cable by the strength of the towers. In this case the aerial cable must be installed as earth rope in replacing the existing earth rope. But for those earth ropes normally steel ropes with 50 mm² and a diameter of about 10 mm are in use. In replacing these earth ropes the power utilities normally use Al/St-ropes with 50/30 mm². This rope has a diameter of 11.65 mm and a weight of 378 kg/km. The new generation of optical fibre aerial cables must come as close as possible to these figures if they will be installed on these old lines. The optical fibre aerial cable described in section 3.2 fulfil these requirements. But for this new construction principles have been developed.

On the other hand not on all power lines which will be erected or upgraded or where the earth rope is replaced will need at the moment optical fibre transmission paths. For this purpose the cable described in section 3.1 was developed where in the centre of the earth rope a tube is incorporated in which at a later stage optical fibre elements can be blown in.

3. New Constructions for Optical Fibre Aerial Cables

With the construction for optical fibre aerial cables described in the following two aims with two different cables are envisaged:

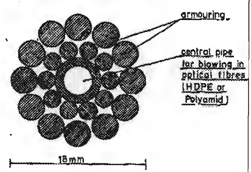
1. To create a ground wire in which in a later stage optical fibres can be incorporated.

2. To create an optical fibre ground wire with the lowest possible diameter increase compared to the bare ground wire.

Both cables are intended for the use with power utilities in addition to the existing optical fibre aerial cables.

3.1 Ground wire with central tube

To enable the user of high tension power lines to incorporate optical fibres in a ground wire in a later stage it is necessary to provide a ground wire with this possibility. To protect fibres from environmental conditions it is advantageous to put the optical fibres respectively the optical fibre element inside the armouring. This is normally done by providing a tube inside the ground wire. To be able to pull in the fibres it is necessary to have the tube as straight as possible. Therefore a central tube will be preferred. The dimensions of this tube depend from the element diameter, and the material of the tube should be chosen in such a way that as less friction as possible between the inner tube wall and the fibre element arise. Moreover the tube must be the base for the armouring with steel and aluminium alloy wires. Out of these considerations the central tube will have an inner diameter of 4 mm with a wall thickness of 1 mm and is made of polyamide. Over this a double layer



95/55 Earthrope I_k = 17,4 kA /0,6 sec.

Construction

Number of fibres : 1 - 4
Central pipe : Inner/Outer diameter = 4/6 mm
Amouring : 1.layer 10 × 2,5 mm steel
2.layer 12 × 3,5 mm ALDREY

Cable diameter : 18 mm
Cable weight : 686 kg/km
Cross section : 164,5 mm²
Aluminum cross section : 115,45 mm²
Steel cross section : 49,10 mm²
Ultimate tensile strength : 94,3 kN
Young's modulus : 89,4 kN/mm²
Nominal short time current (t_a = 20 °C) 1 sec. : 11,9 kA
0,6 sec. : 15,3 kA

Fig. 2: Cross-section and data of ground wire with central tube

armouring is applied. To protect the strength bearing aluminium clad steel wires (Aw) from vibration and other forces these wires are put in the first armouring layer and the second layer is made of aluminium alloy (Ay) with a minimum diameter of 3 mm to avoid damage of these wires by lightning. In the here described cable the Ay-wires are chosen with 3.5 mm diameter.

Out of the armouring the short circuit current of this cable will be 12 kA for 1 second respectively 15.3 kA for 0.6 seconds. Figure 2 shows the cross-section of this cable with the relevant mechanical characteristics. In Figure 3 a photograph of this rope is shown. The aerial cable has a diameter of 18.0 mm and is only 2 mm thicker than a comparable rope Ay/St 95/55, the weight is almost the same and this aerial cable can be installed with the same sag as the other phase ropes. By the lower heat capacity of aerial cables by their plastic inner construction the short circuit current capacity is about 10 % lower than this of the comparable ground wire even if the Ay-portion is higher.

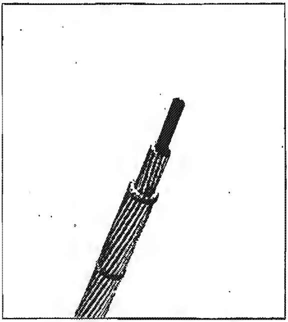


Fig. 3: Ground wire with central tube

This cable is fixed to the towers by spiral armatures to avoid deformation of the inner tube, because such a deformation will disturb the flowing parameters inside the tube severely and the blowing-in will be more difficult.

How does such an optical fibre element look like which can be incorporated in such a tube. It was prefered, that the element will be blown-in instead of pulled-in by a pulling wire. By this the required pulling forces and therefore the strength of the fibre element are limited. But a compression protection for temperature loading will be needed because this element is not fixed to the armouring.

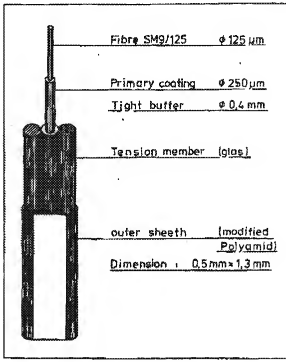


Fig. 4: Single fibre element for blowing-in

The primary coated optical fibre - normally single mode fibre - will be secondary coated by polyamide. For a one fibre element such a fibre is fixed between two FRP members with also 0.4 mm diameter and coated together with a polyamide sheath which leads to a diameter of 1.3 mm (Figure 4). Also a six fibre element will have the same diameter where the FRP member is put in the central and the fibres are stranded around this element. Such an element can be wind on a spool and rewinded for blowing in from this spool (Figure 5 (below)). The other possibility shown in Figure 5 (above) is the cross winding of the element and then allowing the pay-off from the inner side of the spool with no rotation of the whole fibre spool. In the latter case the dynamic force on the fibre in the upwinding process is much lower and independent from the total length of the fibre. Therefore this cross winding technique was chosen. It is possible of cross winding about 5000 m of such an optical fibre element.

The required apparatus to blow-in the fibre element is shown in Figure 6. With a maximum pressure of 30 bar in this attempt 1000 m of a one fibre element are blown-in in an installed ground wire with a central tube. During and after the blowing-in no change in attenuation at 1300 nm and at 1550 nm were observed (Figure 7). Also at pulling forces up to the maximum permissible load of 38 kN no change in attenuation arises. For temperature loading the bare fibre element winded on a cross

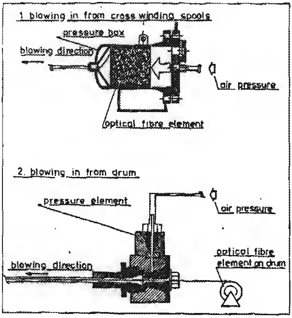


Fig. 5: Principles for the blowing-in apparatus

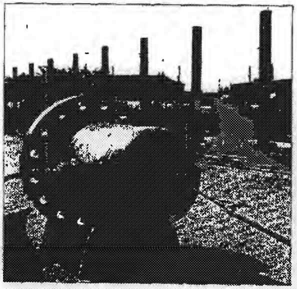


Fig. 6: High pressure blowing-in apparatus for cross winding spools adopted to the ground wire

winding spool were tested. By the lateral forces of the winding pressure such test is even more severe than testing it on an installed cable. The test installation and the results at 1300 and 1550 nm are shown in Figure 8 respectively 9. Only at 1550 nm and -40 °C slight increases in attenuation are seen.

By the promising results of these tests a larger field trial over a length of approximately 12 km will be carried out in 1990 to get experience from real installation and on long term behaviour before those systems will be installed on a regular basis. The armatures and the closures for those cables are identical to those of conventional aerial cables.

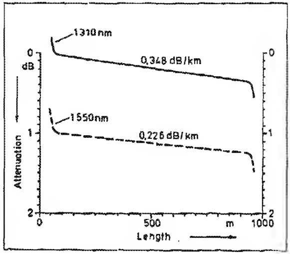


Fig. 7: Attenuation of fibre after being blown-in

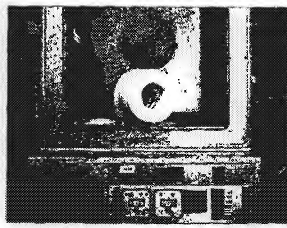


Fig. 8: Test set-up for temperature cycling with cross winding spool

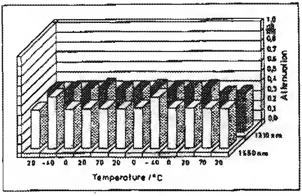


Fig. 9: Results from temperature cycling for cross-winded fibre element

3.2 Optical Fibre Ground Wire

Optical fibre aerial cables up to now consist of a dielectric optical fibre core with polyethylene sheath and a diameter between 7 and 11 mm. An one or double layer armouring is applied over this sheath. This means that optical fibre aerial cables have a diameter over armouring of at least 15 mm independent from the armouring.

On old power lines normally the existing ground wires with 50 mm² steel are replaced by ground wires Ay/St 50/30 or Ay/St 70/12 with a diameter of 11.65 mm respectively 11.72 mm. Their weight is 378 kg/km respectively 284 kg/km. To get optical fibre ground wires with diameters in this range the cross-section of the fibre element must be reduced drastically. But the operational range of the fibres must not be reduced because the requirement for a 5 to 4 °/₀₀ operational range still remains. From this point it seems reasonable to replace steel or aluminium alloy wires by optical fibre buffers with the same diameter. But these buffers

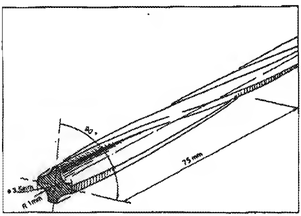
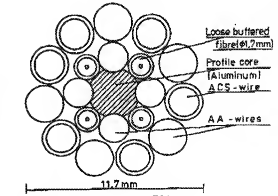


Fig. 10: Profile core for optical fibre ground wire



Cable Type: ASLH-Wb 4E9/125

Construction

Number of fibres	: 4 - 12
Cable diameter	: 11,7 mm
Cable weight	: 332 kg/km
Supporting cross section	: 66,6 mm²
Central profile core(Aluminum)	3,0 mm
Aluminum alloy wires	: 1.Layer : 4 × 2,0 mm
	2.Layer : 5 × 2,5 mm
Aluminum cladded steel wires	: 2.Layer 6 × 2,5 mm
Ultimate tensile strength	: 44,7kN
Young's modulus	: 104,1kN/mm²

Fig. 11: Optical fibre ground wire with profile central element

cannot be arranged centrally because in this case the operational range could not be achieved. As outlined before the laylength of the optical fibre buffer must be in the range of 70 to 80 mm to achieve the required operational range. This is for steel wires to short. Moreover it can be said that the aerial cable must be fixed on the towers with spiral armatures to avoid lateral forces on the fibre element. This means the steel elements should be as far as possible to the outer layers of the armouring.

These considerations led to the new developed optical fibre ground wire in which the central element is the most important element. In the stranding process as central element an aluminium profile is rolled to form hollow grooves (Fig. 10) and in the same process stage the first layer of aluminium alloy wires is stranded in the formed grooves and between these aluminium alloy wires optical fibre buffers are stranded. This construction prevents the optical fibre buffers from dislocation forces. In the same stranding process from a second cage a layer of Ay and Aw wires are stranded in the opposite direction. By this the optical fibre buffers are protected in chambers formed from the aluminium profile, the Ay/Aw wires of the first and second layer.

This cable with 4 optical fibre buffers can keep per buffer a maximum of 4 fibres so that with this construction up to 16 fibre ground wires are possible. And this cable is with 11.7 mm as thick as the bare ground wires Ay/St 50/30 respectively Ay/St 70/12. The weight is with 332 kg/km between the two before-mentioned ground wires. By the cross-section of aluminium and aluminium alloy the short circuit current for 1 second reaches 5.7 kA and 7.4 kA for 0.6 seconds.

Fig. 12: Steel tube buffer with 4 single mode fibres

Besides forming the central profile wire the construction of the buffers is of primary importance. Up to now normally as buffer material an extruded plastic material is used. For the abovementioned cable a tube with inner diameter of 1.2 mm and an outer diameter of 1.7 mm is adequate. But on the other hand also steel tubes can be used. Such a steel tube is made in forming a steel tape to a tube and welding it by a laser beam. In this case tapes with 0,15 mm thickness can be used so that a tube of 1.4/1.7 mm can be formed. In both cases the tube will be filled with jelly. By the expected lateral forces during service and the pulling forces during the fabrication on normal steel wire stranding machines the steel tube is preferable. Figure 12 shows such a steel tube with 4 fibres. An additional advantage of this steel tube is the higher inner diameter which leads to a larger operational range for the same laying length or the possibility to have a larger laying length giving the same operational range but with better performances at 1550 nm by a larger bending radius. Figure 13 shows a photograph of the entire cable. During the fabrication process no additional attenuation arises at 1300 and 1550 nm. Further results on this cable will be reported on the symposium.

After tests in the laboratories and the internal test field, field trials are foreseen for 1990. For these field trials some modifications have to be done on the hood closure for the cable inlet to achieve tight closures.

4. Outlook

By these new developed optical fibre ground wires new possibilities for power utilities arise. Now for all overhead power lines adequate ground wires are available. Whereas for 220 and 380 kV lines the standard optical fibre aerial cable with conventional fibre core will be used it will be possible for 110 kV lines to replace the existing earth wire by a thin optical fibre ground wire with no additional loading on the towers or add a separate aerial cable on 20 kV lines. On the other hand it is possible to install on other power lines ground wires with a central tube for cases where at the moment no optical fibres are needed. At the time of need optical fibre elements can be incorporated with less effort.

Also in other countries cable manufacturers and power utilities work in this subject [4].

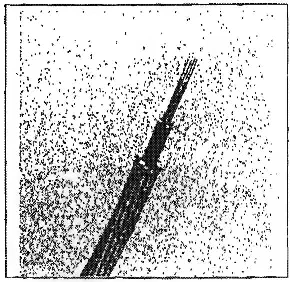


Fig. 13: Optical fibre ground wire

5. Literature

[1] Jürdens C., H. G. Haag, R. Buchwald, Experience with Optical Fibre Aerial Cables on High Tension Power Lines, CIGRE, Sec. 22-11, Paris 1988

[2] Oestreich U., H. Nassar, Self-Supporting dielectric Fiber Optic Cables in High-Voltage Lines, 37th IWCS 1988, 79 pp

[3] Schneider J.M., J. Schmelter, R. Herff, Optical Ground Wire Design with a Minimum of Dielectrics, 37th IWCS 1988, 83 pp

[4] Kawasaki M., et al., Suitable Design and Characteristics of Optical Ground Wire for 1.55 µm wavelength, 37th IWCS 1988, 93 pp

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